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CONTRIBUTIONS ON THE CLIMATE OF THE BERN ENVIRONS: SELECTED PROBLEMS AND PRELIMINARY RESULTS

B. Messerli, A. Krummen, R. Maurer, P. Messerli, H. Wanner
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Translation of "Beiträge zum Klima des Raumes Bern: Ausgewählte Probleme und vorlaufige Ergebnisse," Yearbook of the Geographical Society of Bern (Jahrbuch der Geographischen Gesellschaft Bern), Vol. 50/1970-72, pp. 45-78

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16. Abstract The importance of and methods for studying the interaction of man and the meteorological environment are discussed. Insolation, considered the most important factor relating to the bioclimate and urban planning, is mapped over part of the Bern conurbation . Other information analyzed as a function of time and topography includes wind patterns, temperature curves, snow coverage and its duration, and data obtained from satellite photos taken in different regions of the spectrum. Requirements are outlined for a network of stations to measure parameters affecting climate and air pollution, and for processing systems to allow extrapolation with respect to both time and location.

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CONTRIBUTIONS ON THE CLIMATE OF THE BERN ENVIRONS: SELECTED PROBLEMS AND PRELIMINARY RESULTS

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1. Problem (B. Messerli) /45*

In 1939, about 36% of the Swiss population lived in urban areas, 43% in 1950, and as many as 58% by the last census in 1970. A pronounced change in structure is indicated by these few statistics. Thus 58% or 3.6 million individuals live in cities and conurbations (data and definitions based on ESTA, 1972) at this time, i.e., 58% of the population lives on only 9% or 3587 km^2 of Switzerland's total area. For the Bern conurbation, this means 285,000 people in an area of 273 km^2, and the extensive construction projects of the upcoming years indicate that this process of increasing urbanization is far from coming to an end. Our future tasks can be derived from this: Increasing population concentration at a few locations also calls for an increasing concentration in our work and our responsibility at these locations. Above all, however, we must understand, in our thinking and planning processes, that an urban area consists not only of buildings, streets and economic activities, but especially of human beings who must still maintain some sort of relationship with nature (cf. Spiegelberg, 1972). Basic questions have been raised: _

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* Numbers in the margin indicate pagination in the foreign text.

How have the extensive structural changes in our metropolitan areas effected environmental conditions and how must environmental conditions be taken into consideration in future structural changes?

We have concentrated on a limited area of this complex of problems: Climatological and atmospheric-hygiene conditions in terms of application, i.e. with their relationships to the city and its environs, to the human being and his requirements. Fig. 1 clearly shows this relation, and quite varied aspects of it will be discussed in the following section. We should give primary consideration, however, to the fact that without an understanding of thermal conditions and circulation mechanisms, it is not possible to characterize and forecast atmospheric-hygiene processes. The global statement that heating oil and gasoline are the most serious pollutants does not make the same impression as when we /47 state that in the US, annual immission of dust and soot amounts to 16.9 million tons, sulfur dioxide 29.5 million tons and carbon monoxide 75.5 million tons. But if we just consider the last two of these noxáe, we find that Zurich, for example, exhibits immission levels relative to its number of inhabitants which correspond to those of Washington, Philadelphia and Chicago (Müller 1969; Grandjean 1972). Bern's maximum daily and hourly SO_2 averages are also directly comparable to those of large cities in other industrial nations (Städt. Gesundheitsdirektion [Municipal Public Health Administration] 1971), however, and tolerable CO values have temporarily been exceeded in a number of heavily used streets in our city. Are we acknowledging these problems and incorporating them into our planning? What happens in the Eigerplatz depression, highly endangered by inversion, if the South Quarter is now said to already produce 110,000 trips with private automobiles and 110,000 trips with public transportation vehicles daily (Agregger 1972)? Do we understand the thermal stratification of air above the city and ventilation processes under various weather conditions, and have we considered this in selecting the locations of emitters of odors, pollutants and noxae (sewage treatment, refuse burning, superhighways in residential areas, industrial facilities, etc.)? Will the locations of future residential, recreational, industrial and transportational areas be determined exclusively by economic and political factors, or are we willing and able to establish other priorities?

A large number of questions have been raised; we wish to limit ourselves to the climatological aspects. A part of our study program is merely beginning; an extensive measurement network has just been completed. The results that have been collected are not yet adequate for significant evaluation. Thus the subtitle to this work: Selected Problems and Preliminary Results.

2. Insolation Time, Cloudiness and Fog in the SE Bern Area

(Enclosure: Map 1) (H. Wanner and A. Krummen)

2.1. The Importance of Insolation as a Climatological Element

Insolation assumes a particularly important position among the climatological factors which are relevant to the evaluation of a given area. Geiger (1961:5) states the following in this regard: "Among all of the meteorological elements, radiation undoubtedly assumes the uppermost position, because solar radiation is the basis of our life, the driving engine of our atmosphere, and because the earth maintains an energy exchange with the cosmos only through radiation."

Accurate radiation measurements call for a large instrumental and scientific outlay, yet valid answers to the question of insolation can still be found with the aid of measurements of insolation times. Present-day area planning and bioclimatic work clearly indicates the significance of such problems. Mäder (1970:8) likewise places insolation at the head of climate data used for evaluating the "Climate suitability map for housing and recreation" of the ORL Institute.

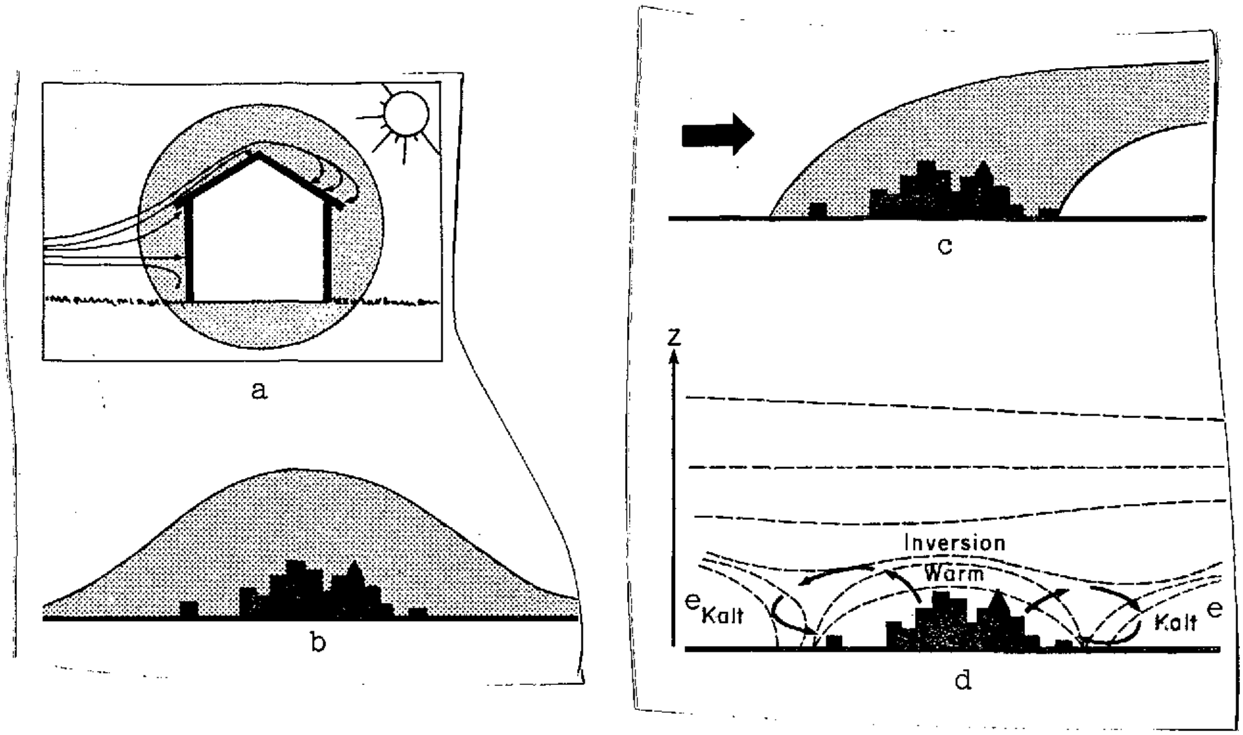


Fig. 1. Human surface modifications and its climatic effects (Ryd 1970, Landsberg 1970, MIT 1971).
a. The climatological effect of a single object.
b. "Thermal island" over a city under still wind conditions.
c. Displacement of the "thermal island" and air pollution by regional wind effects.
d. The development of a stable circulation pattern under special weather conditions.
e. Cold

Since time and funds were hardly available in our case to conduct radiation studies, we decided to concentrate on the question of insolation time in order to provide a basis for climate evaluation for the area studied. It also appeared useful to us to include the problems of fog and cloudiness, since these climate elements directly affect the length of insolation effects. /48

2.2. Explanation of Terms Used

The goal of all measurements is information on how many hours of sunshine we can expect at various points in the area covered, i.e. a knowledge of actual insolation time per year. We must therefore know the three factors exactly which determine the number of hours of yearly sunshine:

a) geographic latitude of the area studied,
b) masking by the surrounding horizon,
c) reduction of insolation time by clouding and fog.

Factors a and b normally remain constant for a given location (exceptions: the clearing of woodlands, construction of buildings, etc.). In the case of item c, on the other hand, quite large variations can occur. Since adequate measurements of insolation time (the standard period covers 30 years) are available for Bern only from the Meteorological Observatory of the University (Bern station of the MZA [Central Meteorological Laboratory]), we had to find a method for our work which provided information in the shortest amount of time. We therefore measured effective possible insolation time, which tells us how long the sun would shine under completely cloud-free and fog-free conditions during a given time interval. This method is also recommended by Knoch (1963:17), among others, in his instructions for taking national climate records.

It was of interest to make a comparison with the values which would apply to Bern (47°N) if we assume the terrain to be completely flat, with no restriction caused by surrounding elevated horizons: we designate this astronomically possible insolation time.

As mentioned, insolation time measurements are being made at the Meteorological Observatory (since 1886). We are therefore able to estimate cloud and fog conditions for this location (Schüepp 1962: 1, 13). This is done with data on relative insolation time, which tells us how long the sun actually shines, on the average, in percent of the effective possible insolation time for a given time interval. The difference between this figure and 100% in this case provides information as to the fraction made up of clouding and fog.

This brings us finally to the term fog day. We speak of fog when horizontal visibility is less than 1 km as a result of suspended water droplets. The term "fog day" refers to every day on which fog can be registered at some time.

2.3. Measurement Methods Applied /49

In the case of relative insolation time, we used MZA calculations as our basis (Schüepp 1962: 34). For plotting effective possible insolation time, we had to select an instrument which permitted both monthly and yearly hours of insolation to be calculated in the most efficient manner possible. We therefore decided on De Quervain's (1957) "daytime arc recorder," which that author characterizes as follows: "This is a recording theodolite. As the telescope scans the horizon, the instruments plots the entire field swept by the "daytime arc" as a diagram transformed in such a manner that the "daytime arcs" appear as equidistant lines. Measurement with a planimeter is then all that is needed to determine possible insolation totals for any time interval."

In spite of the small study area (49 km^2), whose topography also exhibits no excessive variations, it proved necessary to take measurements at two or three points per km^2, in view of the plotting which was planned; this resulted in a total number of 128 measurement points and called for the expenditure of much time. The principal question in horizon recording was that of determining precision:

-- Since each measurement point had to be considered representative of a given area, individual nearby houses and trees which masked the more distant horizon were eliminated for the sake of obtaining a general value.

-- Recording proved very difficult in the heavily-builtup area: It only appeared reasonable to perform measurements on roofs so as to thereby determine insolation time more precisely for an imaginary flat surface lying about 20 m above the ground.

-- A particular problem was presented by the woods: Since measurements could not be taken here, they were not evaluated on the map. The values decrease rapidly toward the edge of a wooded area, depending upon the location of the edge and the slope of the terrain. For reasons of both time and mapping technique, it was not possible to measure variation in insolation time at all of the wooded margins.

-- Where the terrain experiences extreme variations, it is often found that insolation time varies markedly within an extremely short area. These details could not be represented precisely. At best, they can be recognized on the map on the basis of color change (cf. Map 1).

-- A precision of ±2% was achieved in the daytime arc measurements and planimetry.

In the case of fog, quite serious problems arose because of the nonuniform data. Extended series of measurements exist here only from the Meteorological Observatory and from the Bern airport. They reflect the estimate errors which cannot be avoided with fog and the appreciable local differences in fog distribution, which produce an extremely complex picture as a function of weather conditions. The above-mentioned series of measurements were supplemented with two-year observations in the climate research network at the Geographic Institute. The last gaps had to be closed with large numbers of our own observations and inquiries.

2.4. Commentary on the Map (Map 1 in the Enclosures) /50

2.4.1. Effective Possible Insolation Time

The map of effective possible insolation time first of all shows us the spatial distribution of annual values in colors. The color red marks areas with many hours annually, while blue indicates inclement conditions.

Further differentiation could be achieved for representative measurement points with the aid of a digital code. For this purpose, the number of effective possible insolation hours was determined for mornings and afternoons during the summer and winter half-years. The value of each of these four subtotals out of the annual total was then indicated in percent of the astronomically possible insolation time in each case (example: 9.8.6.5. -- The 5 in the fourth place indicates that the effective possible time during afternoons in the winter half-year must lie between 50 and 60% of the astronomically possible time).

When planimetric processing was applied, an approximate value of 4440 hours was determined for astronomically possible insolation time (exact value: 4472 hours). Broken down into the four time intervals used, this yields the following figures:

mornings, summer half-year	1240 hours
afternoons, summer half-year	1430 hours
mornings, winter half-year	790 hours
afternoons, winter half-year	980 hours

2.4.2. Relative Insolation Time

The isopleth mode of representation shows us the distributions, with respect to the time of day, of relative insolation time during the course of the year. We can read off approximately how the average bulk of cloudiness can occur for a given time (very cloudy: blue; slight cloudy: red). Fog times are of course also included in the data on relative insolation time, since the evaluation of insolation autographs is involved here. The question which always arises here is for what area the data on relative insolation time can be considered representative. In the case of the area studied, distinct differences already occur just as the result of the fog. We will obtain informative results in the future if we measure insolation time at various points in the city (cf. Map 2).

2.4.3. Fog

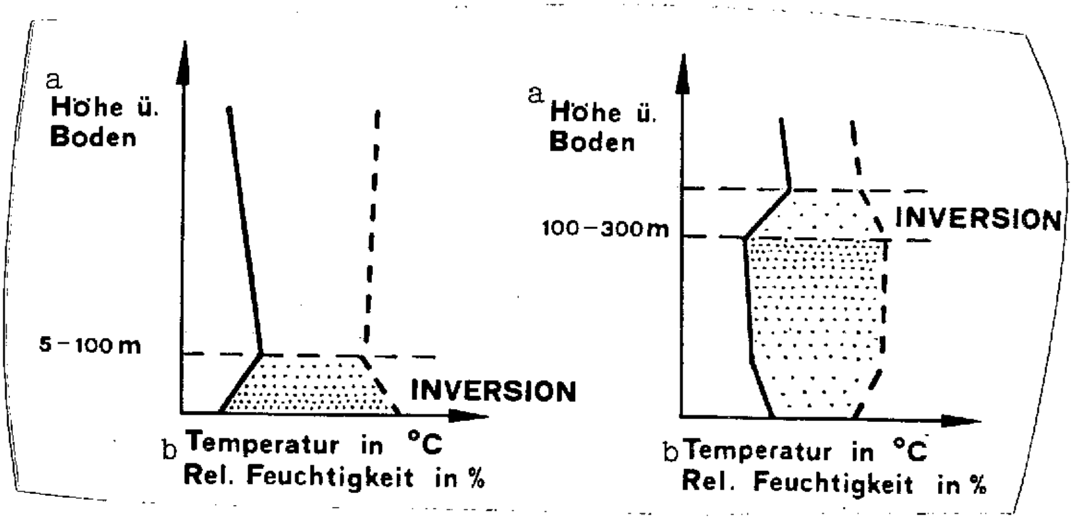
Five zones with different general fog conditions were first outlined in the form of reference levels (red: little fog; blue: zones with much fog). The problem was then to estimate the frequency of occurrence of the three most important types of fog in each zone. It is necessary to keep in mind here that clearly boundaries seldom occur in the terrain and that specific weather conditions are frequently responsible for the development of /51 certain fog situations. The data collected by Schirmer (1970: 135), who delimited the three most frequent types of fog in a similar manner, prove to be of particularly great methodological assistance.

Ground Fog (Radiation Fog with Ground Inversion)

Ground fogs form primarily in the autumn and winter as high-pressure conditions set in: During clear, windless nights, low-lying strata cool off markedly. The cool and therefore heavy air masses flow into the moist low-lying areas of the midland (e.g.

Belp swamp), where condensation occurs during the evening hours (ground inversion: see Fig. 2).

Ground fog High fog



Legend: ——— Temperature
------ Humidity

Fig. 2.

Key: a. Altitude above ground
b. Temperature in °C, relative humidity in %

Example: high-radiation night of February 21, 1972, taken at 10 PM.

Gürtendörfli:	3.2°C	83% hum.	clear
Belp swamp:	0.8°C	94% hum.	light fog

High Fog (Radiation Fog with Elevated Inversion)

High fogs occur in late autumn and particularly in the winter. Their appearance is likewise connected with high-pressure conditions. In our area, they can form primarily in two ways:

-- due to condensation at the interface between moist, hazy cold air in a valley and warmer, higher strata (a distinct hazy surface is usually recognizable), a layer is formed /52 on which sunlight is reflected (development of high-altitude inversion);

-- due to raising of the dense ground fog cover, a high-altitude inversion likewise occurs as the result of heating during the course of the day. The density of the high fog increases with altitude, in contrast to ground fog (Fig. 2). If the high pressure and lack of wind persist, the unpleasant high fog cover can last for days over the midland area ("sea of fog").

"Slope Fog"

This type of fog, sometimes also referred to as cloud or bad weather fog, occurs only rarely in low-lying areas. These are low clouds which reach the ground during poor weather and convective air movements. Slope fogs can occur in any season, but they can be expected more frequently in lower locations during the winter half of the year.

Finally, it should be noted that dense clouds of fog can be infrequently observed along the course of the Aare, the origin of which should be studied with greater care.

2.5. Information Content of the Map

2.5.1. The Evaluation of Insolation Time

Color coding of the map of effective insolation times above all permits an evaluation of spatial conditions. Exposure-related differences occur here whose characteristics have already been recorded and studied by Knoch (1963). The yearly highs and lows are informative. The means have only a limited orientation value and differ in significance as a function of the problem posed, since masking of the sun by the horizon can occur in different ways during the seasons and times of day. For man, for example, it makes a difference whether insolation time is shortened during a few months or the entire year, whether it occurs on summer mornings or evenings.

The solar effects to be expected can be estimated for this purpose locally with the aid of the digital code and the isopleths for relative insolation time.

Examples of typical results from the map:

-- North-south valleys (Gümligental) receive very little sunshine throughout the year.

-- East-west valleys (Gurtentäli) have a more favorable location; particularly in the summer, insolation time is much longer.

-- Ridges on slopes considerably improve insolation time in the case of inherently unfavorable northern slopes (examples at Niederulmiz).

2.5.2. Evaluation of the Fog Situation /53

In the case of fog, we see a distinct dependence upon relief, the number of fog days decreasing with increasing altitude (effect of ground fog, discontinuous decrease above high-level fog cover). We encounter differences at a given altitude because of the effects of city climates: higher temperatures (thermal immission!) and decreasing relative humidity cause the density of fogs to decrease in the center of metropolitan areas. The fog cover is often probably reduced considerably over these regions as the result of thermal conditions, and it would be interesting if this fact could be studied both numerically and photographically (see Fig. 1).

2.6. Possible Applications for the Map

The map can be used meaningfully if all three modes of representation are studied carefully and related to one another. Only in this way can we see, for example, that the low-lying areas, with their favorable insolation figures, lose some of their value again as the result of fog conditions. In using this approach, we encounter absolute advantages on the high-lying areas favored by sunny conditions that normally still lie above the upper limit of the "sea of fog." These areas are called the "warm slope zone" by many authors.

In closing, let us add a remark concerning the evaluation of such a climatological element in terms of application to planning: Insolation time could play an important role primarily in decisions on residential areas and in the search for recreational and health-resort locations. It also assumes a decisive position among the criteria for suitability which are important to agriculture, along with the questions of temperature and precipitation. In any case, we encounter the problem of time consumption in such studies. We have attempted to work on a modest range of climatological problems within a small study area and have applied several weeks to this. Also consider how many hours of work must be needed if the overall climatic cumulative effect is to be determined within a larger region, as was done by Primault (1972), among others, for the Canton of Vaud. The problem of upgrading efficiency becomes directly apparent. Once we have concerned ourselves, in the case of insolation time, with whether and how actual insolation time can be determined from a limited number of measurements for a given area through computer digitalization, similar problems will be encountered more than ever for more complex climate questions. It would be quite conceivable that an area grid would be employed in the same manner as recently done in our country for economic geography problems (Kilchenmann, Steiner, Matt, Gächter 1972).

3. Wind Conditions in the Bern Area (P. Messerli and R. Maurer) /54

3.1. Urban Climate Problems

The extraordinary importance of wind conditions for the development of a residential-area climate, usually called urban climate, and its extension to the undeveloped environs has been confirmed by various studies (Band 1969, Berg 1957, Topitz 1956; see also Fig. 1). In particular, these studies have shown that a characteristic urban climate which differs from the climate of less densely developed, rural surroundings in the modified behavior of a number of meteorological parameters (temperature, humidity, aerosols, wind strength) can form in a typical manner only in the case of low-wind weather (3 or 4 m/sec) (Berg 1957, Band 1969). This fact can be roughly interpreted in terms of the following model:

If an urban area is assumed to be 7 km across and mean wind velocity is 7 m/sec (Beaufort 4), for example, a quantity of air can be "infected" over a period of just under 17 min in contact with the city. Whether a measurable change in the physical parameters of air masses occurs and thus the climate data measured in the urban area and in the lee of the developed area deviate from those to the windward depends upon this contact time. The effect on the lee area produced by the air heated over the developed area, perhaps made more humid and enriched in turbid media depends not only on the type and size of the developed area but also very appreciably on wind speed -- the effect is also most pronounced here at wind velocities of 2 or 3 m/sec -- as Band (1969) has been able to demonstrate in 31 communities at Cologne Bay, taking various types of development (villages, small industrial cities, one large city) into consideration.

Thus wind plays the decisive role in the development and propagation of the climate associated with each built-up area. Which areas feel the negative effects of the urban climate (air pollution, inadequate ventilation during low-wind weather) more and more as the size of the built-up area increases is a function here of the dominant wind directions. Urban and regional planning without sufficient attention to wind conditions can therefore have catastrophic results. This observation has unfortunately been made in many large cities. Thus a critical review of the maps of several large German cities, for example, indicated that little consideration had been given to climatic conditions in the arrangement of residential and industrial areas relative to one another. The industrial and railroad areas are located in the prevailing windward direction, and the air pollution caused by them is thus carried across the entire city (Caspar 1946, in Knoch 1963).

A study of wind structure in the Basel area (Schüepp 1971) indicated that during fair weather conditions with gentle winds, the polluted air carried away at night flows back into the urban area during the day, causing severe annoyance.

These examples clearly demonstrate the importance which a detailed study of wind conditions in our built-up areas warrants.

3.2. Wind Measurements Taken by the Bern Climatological Station, 1965-1969 (Fig. 3). /55

Hourly values for wind directions and velocities (to the extent available; cf. reference MZA), as well as the gust peaks also determined, were evaluated in terms of frequency statistics

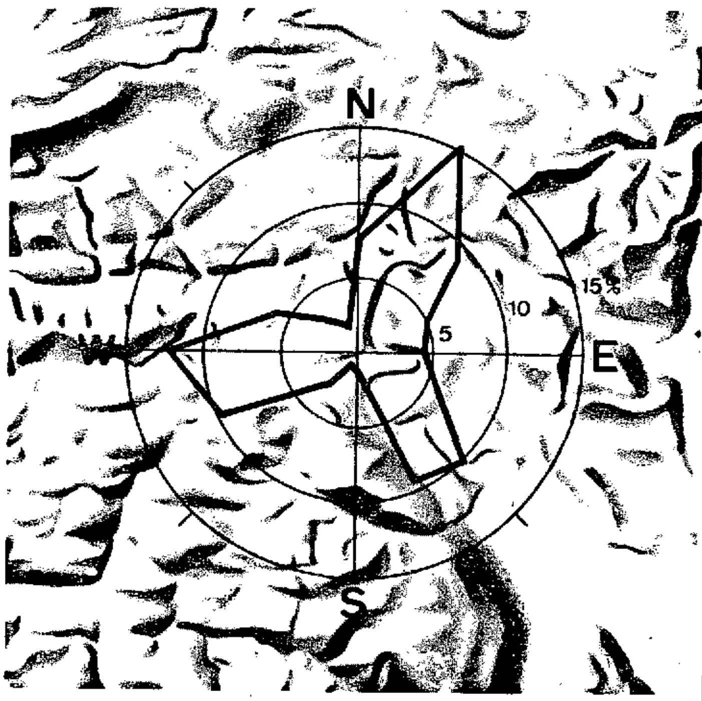


Fig. 3. Mean annual frequencies of principal wind directions, 1965-1969 (subdivision into 16 sectors).

with the goal of determining wind conditions as accurately as possible for the city of Bern on the basis of the recordings of the climatological station. These data made it possible to go beyond the seasonal distribution of the measured quantities and plot the variation in such distributions with the time of day.

This will be explained below, using the example of wind direction.

Fig. 3 shows the mean annual frequencies of principal wind directions, 1965-1969. The three dominant directions correspond to the relief-induced wind lanes -- for west winds, the Wangen Valley and the Wohlen Lake graben; for northeast winds, the corridor of Moosseedorf and Zollikofen; and for south winds, the Aare Valley -- through which the air masses flow into the urban /56 area. Approximately the following mean relative frequencies were obtained here for the three principal sectors:

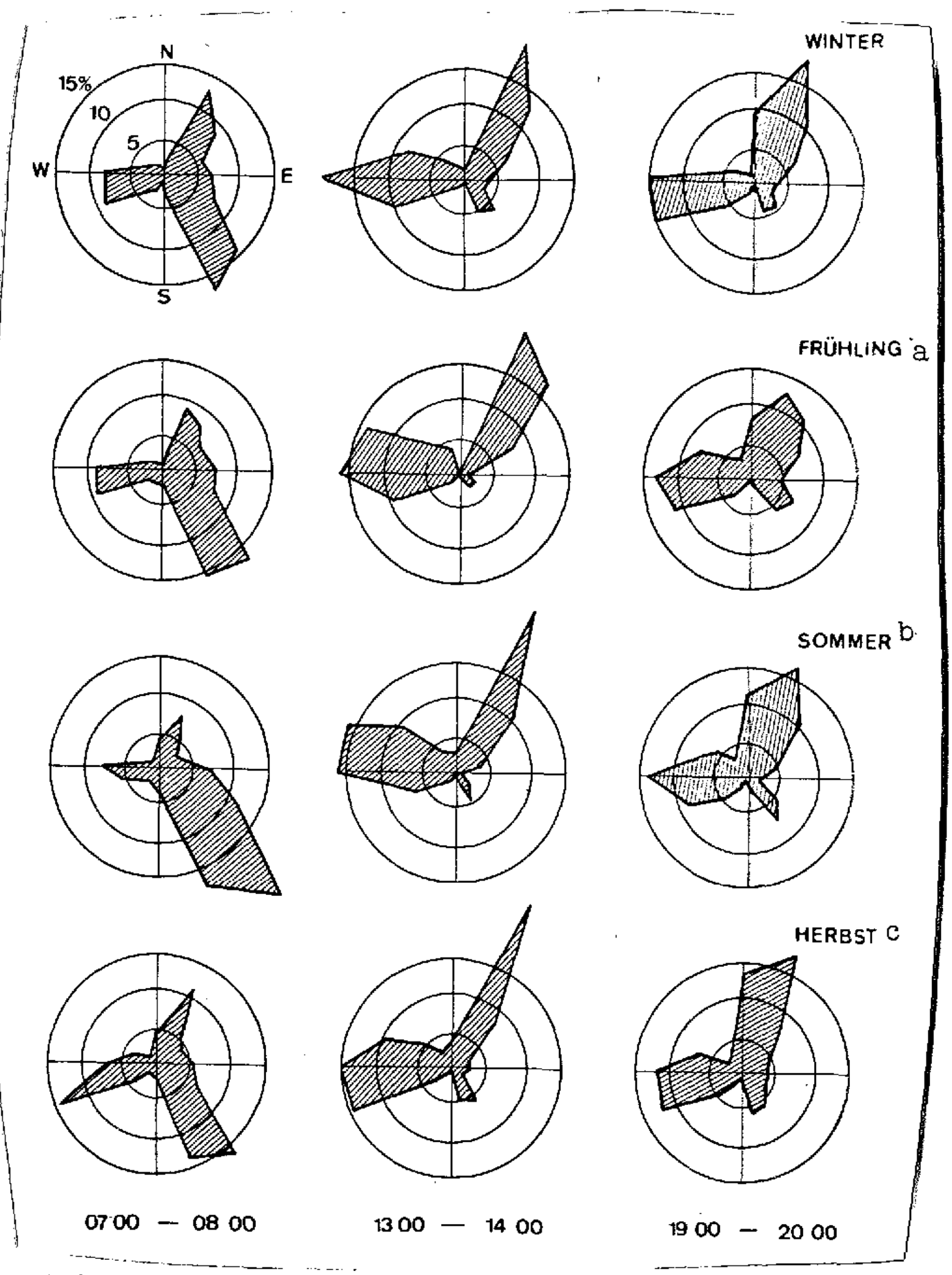
N – NE	: 32 %
WSW – WNW	: 28 %
SE – SSE	: 19 %
total	79 %

This result confirms the pronounced effect on wind direction produced by topographic conditions, but provides no information as to how, for example, the suprisingly high percentage of south winds originate (wind speeds $\leq$ 4 m/sec are involved here almost exclusively; Messerli 1972). The question was therefore checked as to the extent to which this distribution is typical of various times of the day and year.

Daily Behavior of Wind Direction (Fig. 4)

This evaluation is based on hourly values from 7 to 8 AM, 1 to 2 PM and 7 to 8 PM. It can clearly be seen that there is a daily behavior pattern in wind directions which matches a barely discernible seasonal pattern.

The frequency of south winds (Aare Valley winds) could be explained, on the basis of this distribution, by a "valley wind effect." The above-mentioned velocity structure and the daily behavior of these winds suggest that a thermal flow out of the valley occurs at night which reverses during the day in accordance with the principle of mountain and valley breezes. The distinct dominance of south winds during the morning hours, their pronounced dropoff at midday in favor of the two other principal directions, from which the air masses may be drawn up the valley, depending upon weather conditions, and a distinct increase again during the evening hour would permit such an interpretation. The additional occurrence of weak (less than 2 m/sec) north winds during the evening hour should still be noted. The extent to which the thermal island of the city could affect such a thermal flow remains an open question. A ventilation mechanism, which is important for Bern, may be indicated in this daily rhythm, remaining relatively constant throughout the year, in the dominant winds (Fig. 4) which reach the urban area via the topographically determined entry points. The extent to which the system suggested here, which can be important for an adequate renewal of air precisely within the city, actually plays a role will only be learned from a finer



Time (24-hour system)

Fig. 4. Daily behavior of wind directions for the four seasons (1965-1969).

Key: a. Spring
b. Summer
c. Autumn

analysis of the daily behavior of wind direction and velocities under various weather conditions.

Nevertheless, this simple evaluation already provides initial indications of unsuitable locations for new industrial zones, since they could appreciably reduce the effectiveness of the "fresh air supply" to the city if placed at the entry of such a ventilation channel.

3.3. Results of an 80-Day Comparative Series of Measurements Between Bantiger and Bolligen (Fig. 5).

Local ventilation effects, with horizontal and vertical differentiation, must be determined in comparative measurements which are well-planned and limited in time. We shall consider an 80-day study as an example (February 12 to May 2, 1972). It was conducted with electrical wind-measuring instruments developed at /59 the Geographical Institute (WRDS Maurer wind-measurement system). These instruments permitted an exact determination of hourly mean velocity and wind direction time in eight sectors, but required daily reading and maintenance.

The results indicated the following situation (Fig. 5): Wind conditions on the Bantiger are largely independent of relief. A comparison of the results with wind measurements from balloon ascents at Payerne at an altitude of 850 m above ground (about 1450 m above sealevel) indicates that about 75% of all winds above Payerne and at the Bantiger can be compared directly with one another. The only conspicuous deviation is the right rotation of the prevailing SW winds in the Payerne area to a westerly direction on the Bantiger (effect of the Wohlen Lake graben?) Air flow through the Aare Valley is hardly apparent any more at the level of the Bantiger. Since measurements at the Bern MZA station are conspicuously characterized by relatively weak winds in comparison to other midland stations (Station location? Large scale development in the western part of the city? Relief?) and therefore cannot be compared directly with Payerne or Oeschberg, we are provided with an ideal a

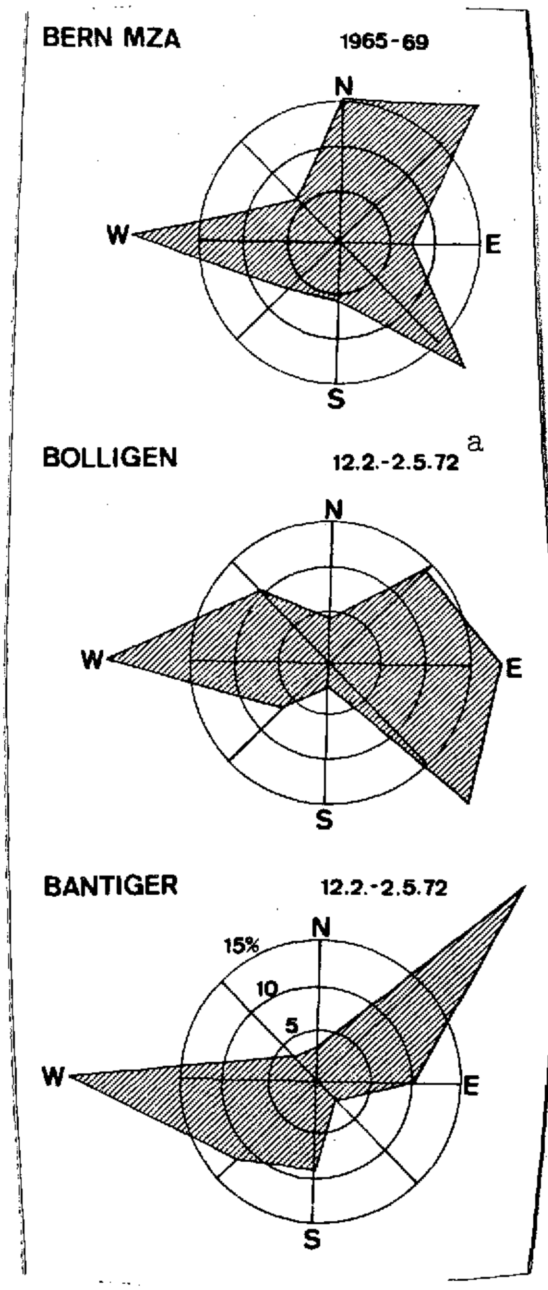


Fig. 5. Comparisons of wind direction.

Key: a. February 12 to May 2, 1972

an ideal secondary monitoring station on the Bantiger in open atmosphere, so to speak, above the city.

The winds in the Bolligen area, on the other hand, are distinctly molded by the relief. Shielding by the Bantiger in the north and the channel effect of the Worblen Valley are the decisive factors. The high percentage of air fed in from the Worblen Valley is of particular interest and would actually have to be taken into consideration in evaluating locations for industrial and residential areas in this region.

Extensive problems have been uncovered in this example; they are to be pursued in the near future at several locations in a comprehensive climatological / atmospheric-hygiene research program.

4. The Problem of Temperature Measurements over Many Years and of Temperature Differentiation in the Bern Area (H. Mathys)

4.1. Bern MZA Station Temperature Readings Over Many Years (Fig. 6)

The mean annual temperature from 1931 to 1960 is 8.5°C for Bern (Schüepp 1961 and 1968; cf. Fig. 6). The monthly means (1931-1960; curve a in Fig. 6) represent a mathematical value with

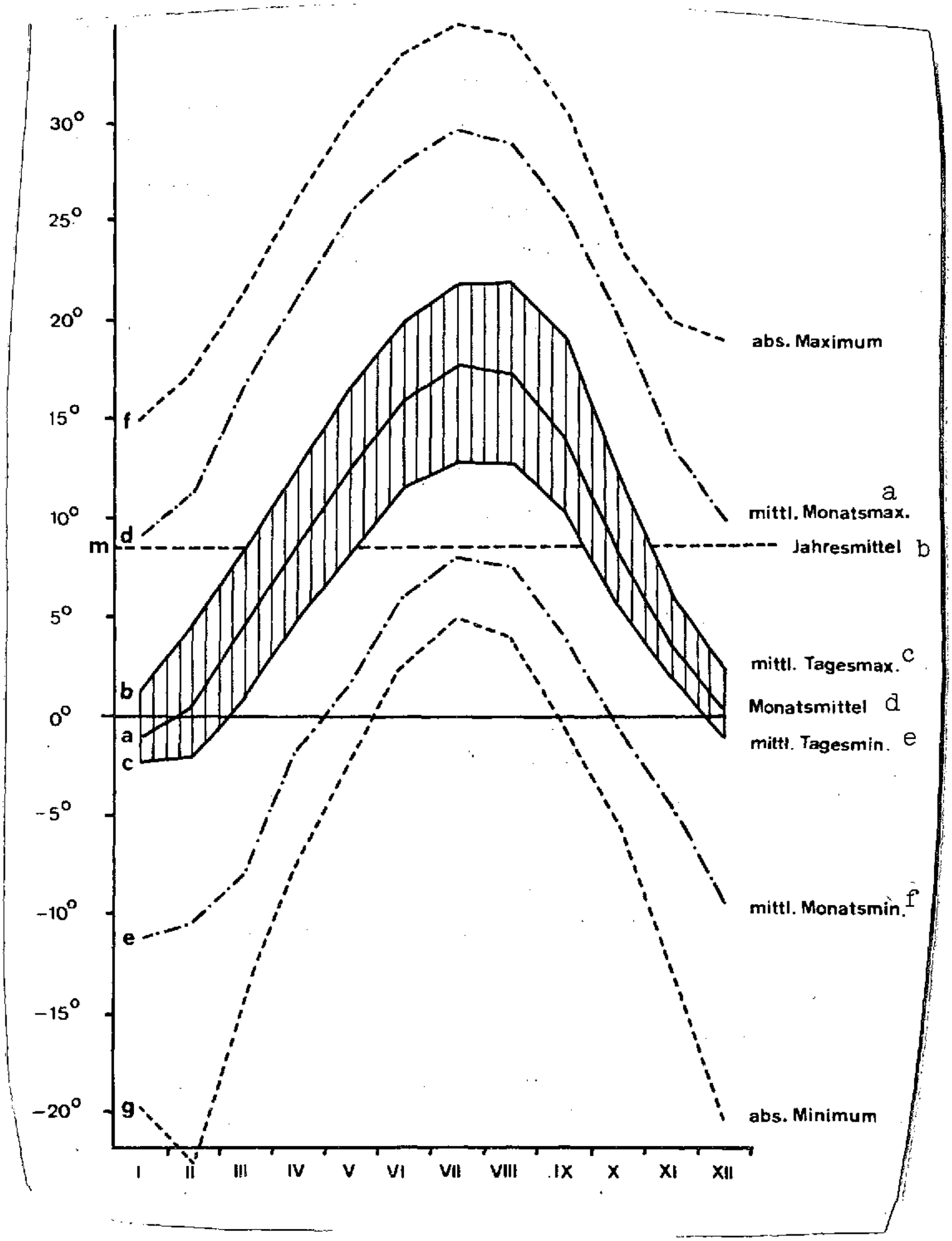


Fig. 6. Bern MZA station temperatures, 1901-1960.

Key: a. Mean monthly maximum
b. Annual mean
c. Mean daily maximum
d. Monthly mean
e. Mean daily minimum
f. Mean monthly minimum

which it is indeed possible to determine fluctuations in climate but from which little information can be obtained regarding effective temperature behavior. The mean daily maxima and minima (1898-1957; curves b and c in Fig. 6) show the range of fluctuation within which we vary as a daily average. It can be clearly seen from this mode of representation that amplitudes are considerably larger in the summer (July/August, up to 9°) than in the winter (December/January 3°). This situation should be extremely interesting in terms of human perception, and should be evaluated in even greater detail in combination with other elements of climate, e.g. humidity (comfort index, damp cold, etc.).

The mean absolute monthly maxima and minima (1901-1960; curves d and e in Fig. 6) show the range of temperature fluctuations which is covered once during a month. The amplitude which is obtained in /61
plotting the absolute peaks (1901-1960; curves f and g in Fig. 6), each observed once in 60 years, is considerably greater. Frequency, distribution and the consistency of extreme values should be studied in even greater detail in the future.

The brief analysis of these series of data does leave the question open, however, as to the extent to which the values from a station are significant for a relatively confined area or even for a region. Is this extremely valuable basic material, covering many years, sufficient for the thermal evaluation of an inner city, a conurbation area or a health-resort area with a more pronounced relief? The following example of the month November, 1972, taken from the new Bern measurement network (Enclosure, Map 2) should provide initial insight into this problem.

4.2. Maxima and Minima in Daily Temperatures during the Month of November, 1972, in the Bern Region (Fig. 7)

During the month of November, 4.8° was calculated to be the monthly mean in Bern (MZA station). Even if we calculate the

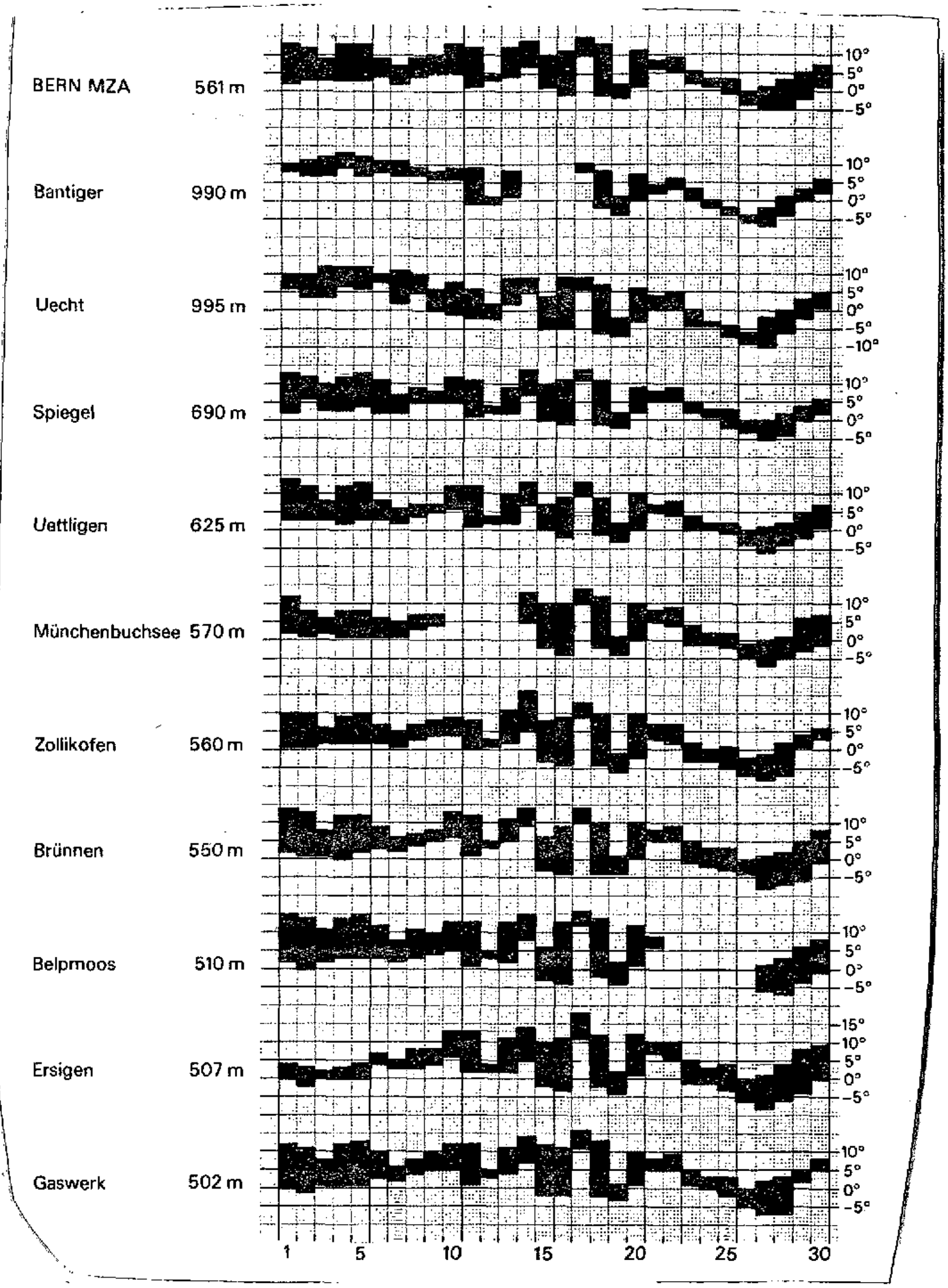


Fig. 7. Daily temperature amplitudes in the Bern region during the month of November, 1972.

daily mean by one of the conventional methods, this figure remains a mathematical value, a purely arithmetic reference number. What we find individuals feel is the maximum and minimum temperatures or, in any case, extreme fluctuations. Fig. 7 clearly shows that the month of November is divided into three sections:

November 1-10: inversion condition; "sea" of fog up to about 700 m, breaking up around midday.

November 11-20: stormy entry of westerlies, with extreme cold and heat.

November 21-30: slow cooling, followed by warming.

Fig. 7 and the comparisons below, all of which come from the city of Bern or its environs, show how cautiously a calculated figure of 4.8° must be assessed for the Bern region. Ample differentiation is found here. Two examples of this:

-- First, a comparison between the Bantiger station, 990 m above sealevel, and the Gaswerk station, 502 m above sealevel:

On five days, the maximum on the Bantiger is higher than below on the Aare; in addition, the minimum up on the Bantiger is even higher than down on Kälte Lake on 9 days. We have the typical autumn inversion condition. During the period of westerlies, the two stations approach one another. During the last phase, the temperatures move in parallel, although small differences in amplitude can be detected. The significance of altitude is beautifully apparent in this example.

-- Secondly, a comparison between the Zollikofen station, in a rural environment at 560 m above sealevel, and the Bern MZA station, 561 m above sealevel:

In the city, the minimum is an average of 1.9° higher than at the Zollikofen "rural station" on 29 days. The minimum for the city actually averages 2.0° higher than that for Zollikofen. We suspect that the thermal island of the city plays a decisive role in this comparison; this should be analyzed in even greater detail during the measurement program in progress and, in particular, should be combined with other climate elements.

5. Snow Coverage Conditions in the Bern Area (1920/21-1969/70) (M. Winiger) /63

A large number of articles have appeared so far on snow conditions in the Alps (including Zingg 1954, Escher 1970, Mosimann 1972), whereas just a few authors have been occupied with evaluating the observations of midland stations. The reasons for this are probably that snow is a phenomenon occurring with regularity at higher locations, of interest to foresters, ecologists, avalanche specialists, climatologists and health-resort directors. In the lower midland area, on the other hand, instantaneous weather conditions primarily determine whether a blanket of snow can form at all and persist for a prolonged period.

Nevertheless, characteristic long-term distributions and patterns can also be recognized in low areas. For the Bern MZA station (Annalen MZA 1920-1970), the number of snow days per winter fluctuated between 10 (1936/37) and 86 (1962/63) during the 50-year period from 1920/21 to 1969/70. On the average, 47 snow days were recorded each winter half-year, a snow day being defined as a day with more than 50% snow coverage in the vicinity of the station at the time of observation (7:30 AM) (Fig. 8).

It can be seen from Fig. 9 that the number of snow days is distributed over an average time interval of 112 days (minimum 18, maximum 192 days) between the first snowfall with the development of snow coverage and the last clearing. But these data, too, are subjected to great fluctuations. Thus as early as October 9, 1920,

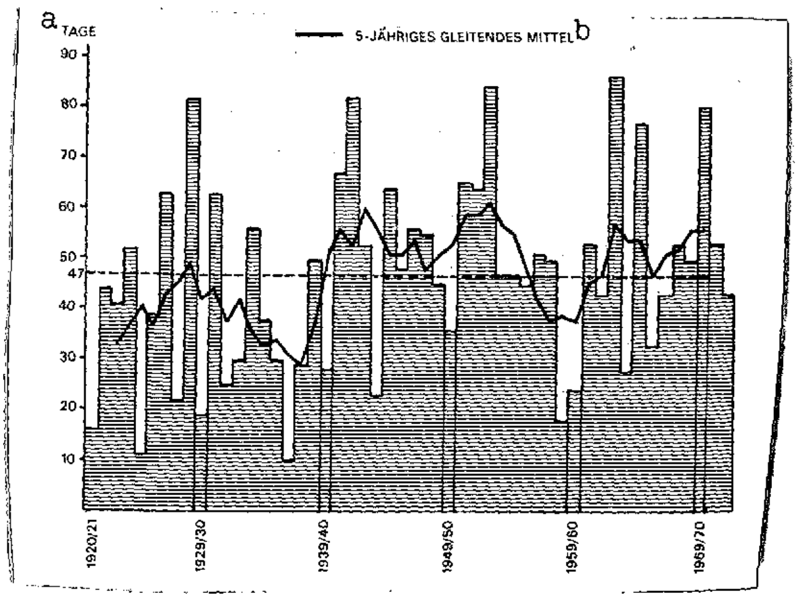


Fig. 8. Number of snow days per winter (1920/21 to 1971/72), Bern MZA.

Key: a. Days; b. Sliding 5-year mean

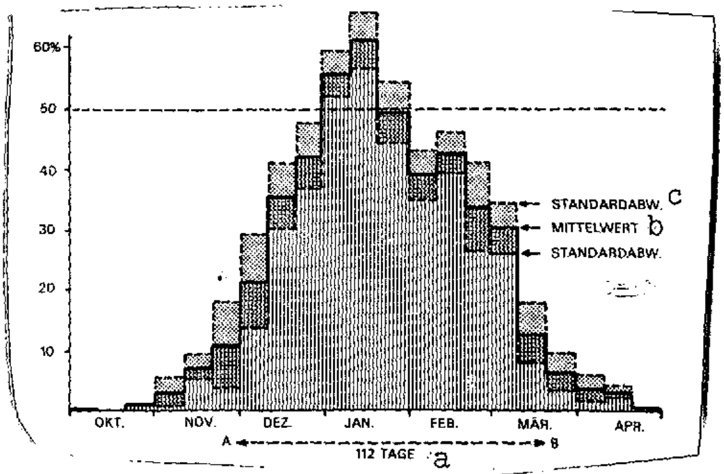


Fig. 9. Mean annual snow distribution at Bern MZA. Mean relative frequency of the presence of a blanket of snow (7:30 AM) in the 50-year mean for winters from 1920/21 to 1969/70 (Bern MZA).

Key: a. Days; b. Mean; c. Standard deviation; A-B. Mean time from first snow blanket to last clearing, average of 47 snow days

the ground was covered with snow for the first time, while in 1926 this did not occur until January 24. On the other hand, no more snow coverage developed after January 21, 1959, a point which was not reached in 1965 until April 21.

In the intermediate years, the blanket of snow is usually of short duration and frequently melts away again within one or two days. On the average for the winter, however, the snow remains for 6.6 days. The longest uninterrupted blanket of snow was observed for 82 days in the winter of 1962/63. Fig. 9 also shows that snow-covered ground can only be expected for 20 days in January with more than 50% probability. The average maximum uninterrupted snow coverage per winter, 24 days, likewise occurs during this month (minimum 3 days, 1936/37).

Where should we seek the causes of these quite extraordinary fluctuations? Precipitation in the form of snow is connected with the passage of fronts; in general, air and ground temperatures should not exceed 0°C if a blanket of snow is to form and persist. The conditions are satisfied only to a highly varying extent for Bern, a typical midland station. In comparison to higher-altitude stations, snow depth is as a rule too low to allow the blanket of snow to survive the onset of warm air, to be expected in all winter months, while, on the other hand, no snowfalls are to be expected during prolonged winter high systems, with the associated low temperatures. In low-lying areas, abundant snowfalls followed immediately by high-pressure systems (inversion with high fog; /66 cf. Fig. 2) must be considered the optimum conditions for the prolonged duration of a blanket of snow, or a situation during which the station is in a region of precipitation-producing polar front advances over an extended time.

The dependence of the presence of a blanket of snow upon the course of weather conditions is apparent from Fig. 10, in which the situation in the winter of 1971/72 is shown (observations of the climate observer network of the Geographic Institute). The date on which altitudes below 900 m were snowed under is November 20, 1970, in all cases. The passage of a front can be seen from the temperature curve for the Bern MZA station, likewise on the other dates on which the blanket of snow formed again over a wide area: December 10, 1971, January 22, 1972, February 14, 1972. Several pronounced onsets of warm air indicate the end of these snow phases each time. This can be observed in particularly pronounced form on December 20, 1971, and in the second week of February, 1972. The transition zone above which a permanent blanket of snow is generally possible can probably be found in the altitude range of about 850 to 1000 m above sealevel. To be sure, considerable regional differences must be taken into consideration here, and even at neighboring observation stations, considerable

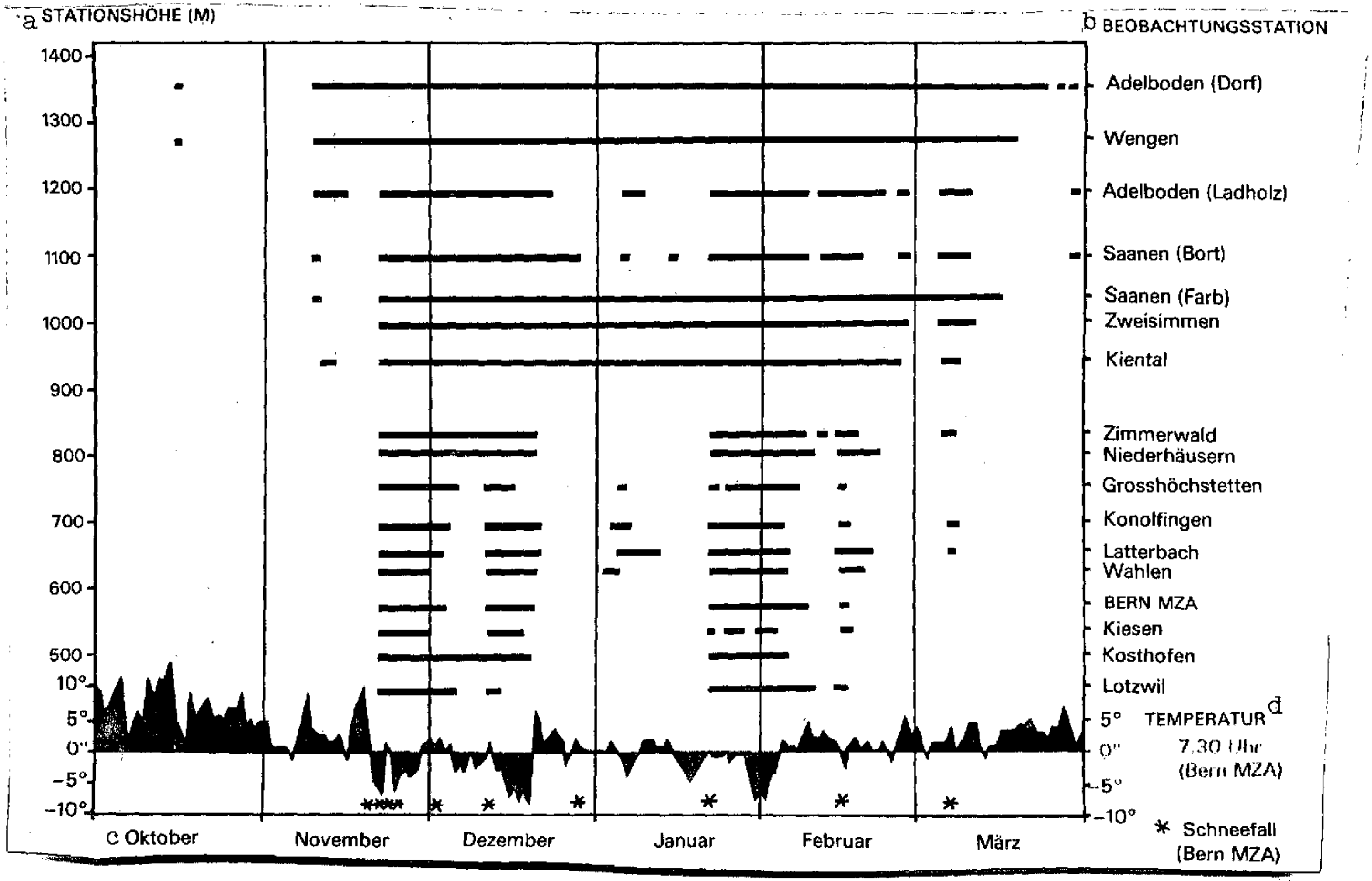


Fig. 10. Days with snow coverage during the winter of 1971/72 for stations at various altitudes (horizontal area).

Key: a. Station altitude (m)
b. Observation station
c. October-March
d. Temperature, 7:30 AM
* Snowfall

differences can occur as a function of the degree of insolation (masking of horizon, direction of valley), as is apparent in the examples of Saanen and Adelboden (Fig. 10).

Thus if we try to explain the great fluctuations in the number of snow days from one year to another in terms of the particularly course of weather conditions, we cannot overlook the fact that conspicuous swings can be seen from the curve of the sliding 5-year mean (Fig. 8) which are also apparent in the comparison of the 18-year mean from 1922/23 to 1939/40 with 39 snow days and 1940/41 to 1957/58 with 55 snow days per winter.

The extent to which fluctuations in climate occur here remains to be established by correlation with various climate elements and values from other midland stations.

To be sure, a comparison of snow data from various stations is problematical in that the location of each observation point appreciably affects the data on the duration of snow coverage. In the future, therefore, it will be necessary to use aerial and satellite photos as additional sources of data in order to be able to properly analyze station data in a region and characterize snow in terms of area.

6. Climate and Earth Observation from Space (M. Winiger)

The launching of TIROS-1, the first meteorological satellite on April 1, 1960, provided the possibility of photographing an almost uninterrupted space/time picture of our entire Earth. Since this date, meteorological events, particularly cloud distribution, have been followed practically without interruption by the wide variety of satellites in the TIROS, ESSA, Nimbus, NOAA and ITOS series.

In addition to clouds, snow and ice conditions over continents and oceans can be determined as meteorological elements. Localization and changes in snow coverage in flat lands, particularly the configuration of the snow line, can be shown to within a few kilometers over large areas, as can ice conditions on oceans and larger inland lakes (for example, cf. Barnes, Bowley 1969, Kaminski 1970). /68

Determination of the snow line in mountainous regions (cf. Photo 1) is considerably more difficult, since large differences in altitude can occur within small horizontal distances; the climatic information content of the location of the snow line thus depends considerably upon the precision of the method of determination. In spite of the relatively low spatial resolution of satellite sensors, which varies between 1 and 5 km, usable methods have been developed here, too, e.g. by Itten (1970; see also WMO 1972), the principle of which is based on a comparison between equal-scale contour maps and the satellite picture. The determination, in terms of altitude, of the mean boundary of a new blanket of snow should be possible over a large area with precisions of up to ±250 m, since its configuration is somewhat parallel to elevation contours on a regional scale. During a melting phase, though, differences occur between the various exposures which in extreme cases can amount to as much as 1000 m, and a mean altitude figure then provides little information.

A decisive phase was initiated when the ERTS-1 (Earth Resources Technology Satellite) was put into operation on July 23, 1972, in that it became possible for the first time to obtain photographs of the middle and higher latitudes at regular time intervals, of the same quality as the well-known Apollo Earth photos. From an altitude of 920 km, two different photographing systems in three and four different ranges, respectively, of the visible spectrum and the near infrared transmit pictures (imageries) which

North

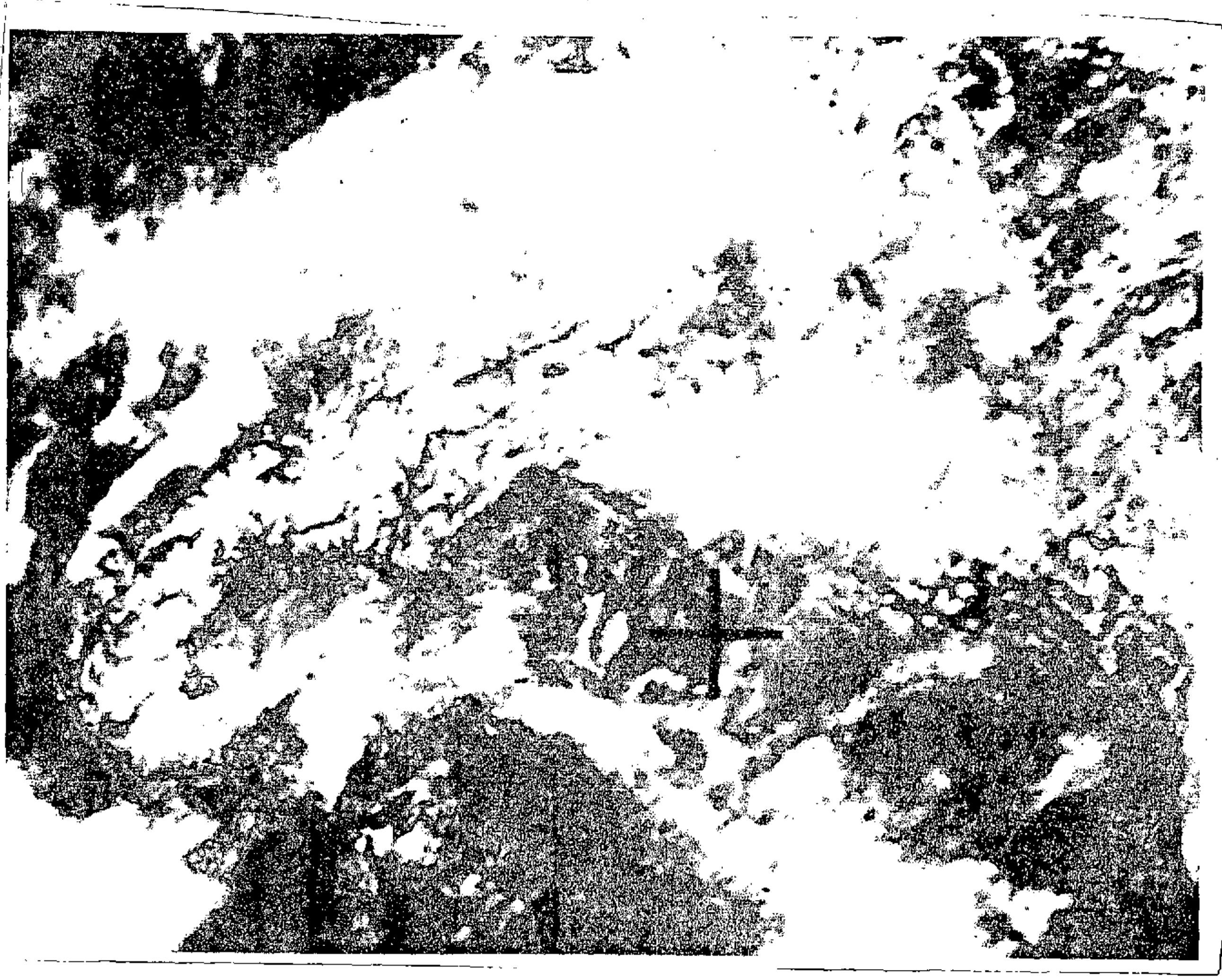


Photo 11. Weather satellite picture of Central Europe (from an altitude of 1440 km). The section shown extends from the Massif Central into the low Hungarian plane, from Rome to Frankfurt. The larger valleys are set off from the snow-covered Alps. The Swiss midland and Southern Germany are covered by fog; the Apennine and Austria are overcast. Photograph (section): ESSA 8, September 20, 1972, 9:42 AM, Ref. No. 17258/2 (APT photograph of the observatory of the city of Bochum).

permit extremely differentiated geographic interpretation with a linear resolution of less than 100 m and thus also determination of the snow line as a function of different exposures.

Photo 2 shows the first picture of the Bern Alps transmitted by ERTS-1. In the spectral ranges of 500-600 µm and 600-700 µm, clouds, fog and snow stand out sharply from the background; in the photograph shown here, forest and pasture sections are easily recognizable even on shaded slopes. Problems can be expected in differentiating among clouds, fog and snow, at any event in areas with rocky, shaded slopes. But if other spectral regions are covered, uncertainties can be eliminated to a large extent. Thus cloud shadows, for example, stand out quite clearly as black spots in the infrared.

The snow lines which can be determined from Photo 2 and differentiated by region and exposure are compiled in the following table for several valleys in the Alps:

Haslital	1650–1800 m
Gadmental	1600–1700 m
Grindelwald	1700–1800 m
Lauterbrunnental	1800–1900 m
Goms	1550–1650 m
Bedretto	1750–1850 m
Engelberg	1550–1600 m
Vorderrheintal (not shown)	1600–1800 m
Simplon (not shown)	2200 m

The differences in snow line altitudes between the various exposures vary within the range of several hundred meters, since snow fell on the previous day down to 1600 m and in some places down to 1450 m. The depth of the snow was only a few centimeters below 2000 m and was sometimes more than 20 cm above this. The extent to which such differences can be read off with high certainty from the satellite picture cannot be stated conclusively here, but it is necessary to interpret all gray areas found in the pictures from the various spectral regions on the basis of a wide variety of orographic and physical characteristics of the particular /70

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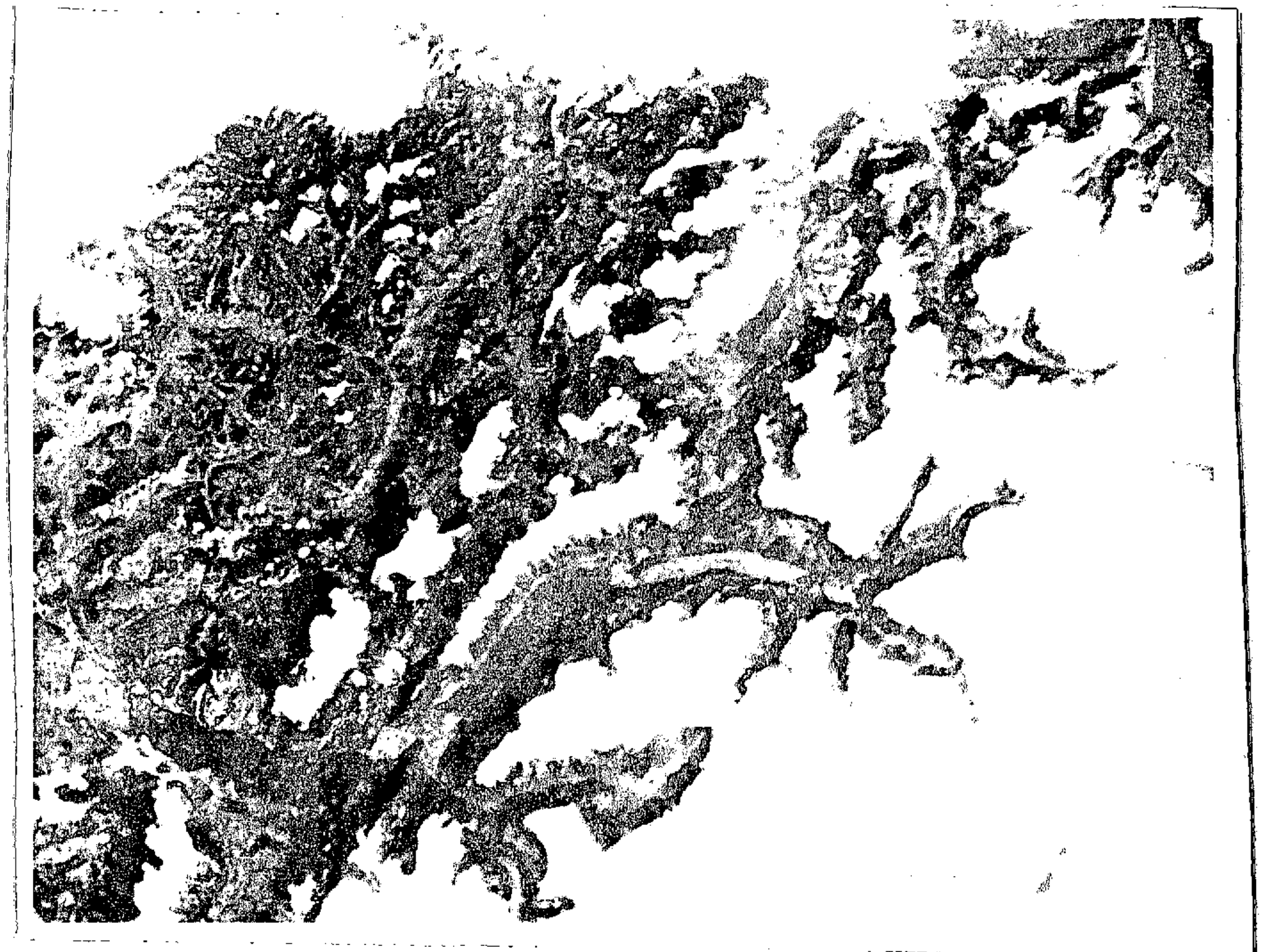

Photo 2. Snow, clouds and fog in satellite picture (from distance of 920 km). There is a new blanket of snow in the high Alps to about 1800 m above sealevel. Thun and Brienz Lakes, the Aare Valley and the Emme Valley are free of clouds; convection clouds are developing along the ridges of the Lower Alps; the midland is enshrouded in fog. Photograph (section): ERTS-1, September 20, 1972, Reference No. 1059-09493-4, MSS 4 (NASA, Goddard Space Flight Center).

point in the terrain. The employment of additional sensors (e.g. thermal-infrared, microwaves, radar) should considerably extend the possibilities for interpretation in the future.

Likewise in Photo 2, a blanket of fog over the midland, in the process of dissolution, can be recognized as a second large-area meteorological element, the upper margin of which is located at 900-1000 m, at the edge of the Jura (not shown). Radiosonde ascents at Payerne (from weather map) confirm this interpretation: a pronounced maximum in humidity was measured at 1000 m above sealevel. The fact that the blanket of fog does not extend farther into the Aare Valley can be attributed to the restructuring process in the weather situation and to wide-area wind conditions, which can only be conditionally interpreted from the satellite picture itself (cloud structures). Photo 1 provides an overview of the weather situation.

Photos 3 and 4 allow a fascinating view of the cloudless midland, while the Jura and Lower Alps exhibit relief-induced clouding associated with slopes on October 9, 1972. The feature which is not sufficiently clear in the infrared region, which is suitable primarily for studying geological structures and the distribution of bodies of water, is the veil of haze over all of the lower regions, with a pronounced thickening between the three Jura lakes, a phenomenon which stands out particularly well in the red (Photo 4) and green areas of the spectrum. The extent to which industrialization of the area affects the moisture and aerosol content of the air has yet to be studied.

Whether the white traces in Murten Lake (Photo 3) can be attributed to water impurities must likewise be left as an open question. With these two references to air and water pollution, however, we begin to emphasize the possibility of monitoring our environmental conditions from the air and from space, too, with suitable sensors and methods in the future and thus analyzing all local observations within the larger framework of atmospheric circulation and spatial relationships.

North

Photo 3. Parts of the Swiss midland and the Jura. The bodies of water, geological structures and forests, as well as the larger conurbations (Bern, Freiburg, Burgdorf, Biel) stand out clearly in this infrared photograph (700-800 μm). Photograph (section): ERTS-1, October 9, 1972, Reference No. 1078-09553-6, MSS 6 (NASA, Goddard Space Flight Center).

7. The Bern Climatological Atmospheric Hygiene Measurement Network and Our Future Tasks (Enclosure: Map 2) (R. Maurer and B. Messerli) /73

For several years, the Municipal Atmospheric Hygiene Office has been operating an intracity measurement network for determining

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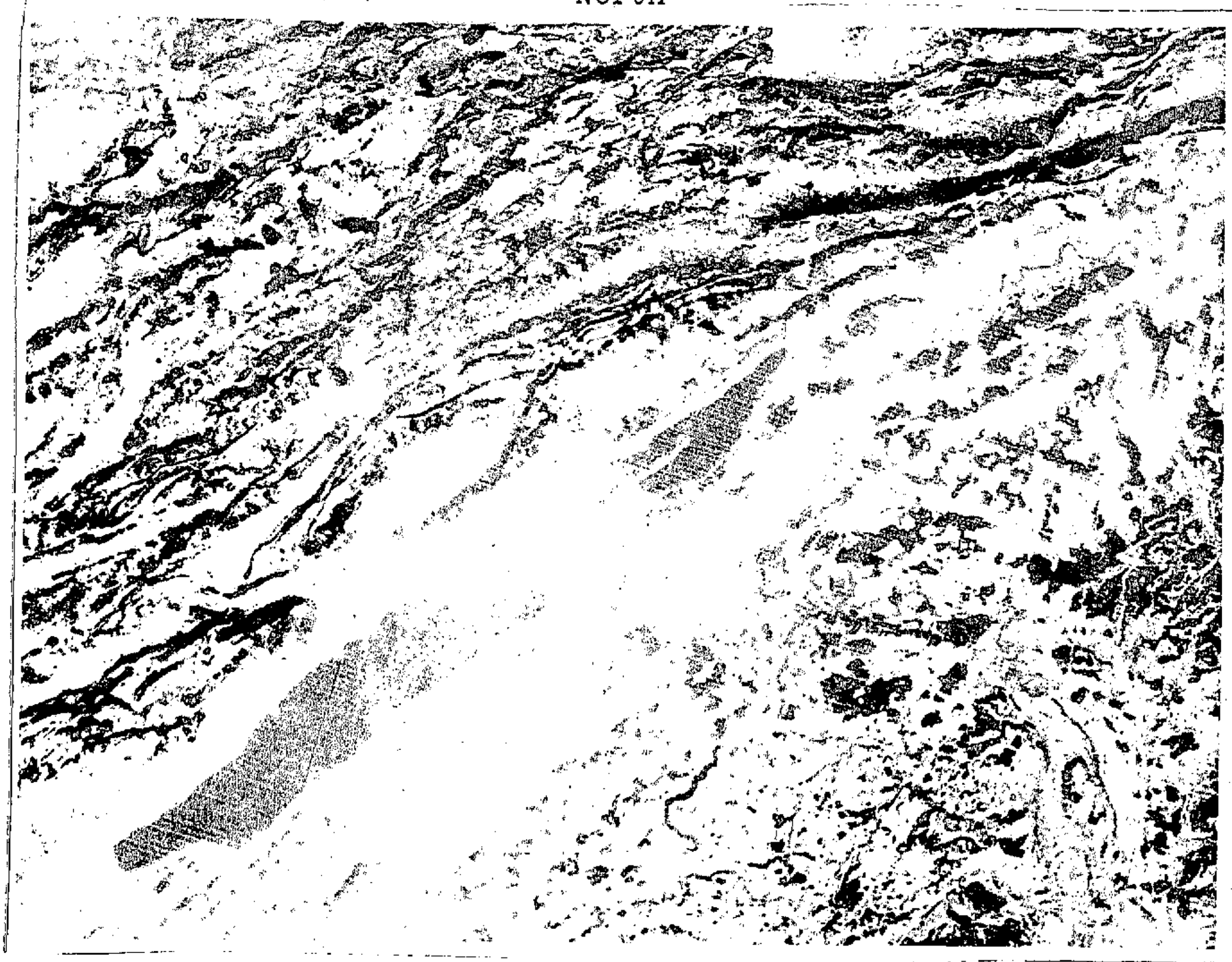

Photo 4. The same area as in Photo 3, but taken in the red region of the spectrum (600-700 m). Forests and clouds are more apparent. The turbidity of the air (perhaps haze) is conspicuous along the Jura, with noticeable thickening at the center between the three lakes. Is this process enhanced by industrial concentrations in this area? Photograph (section): ERTS-1, October 9, 1972, Reference No. 1078-09553-5, MSS 5 (NASA, Goddard Space Flight Center).

the SO_2 content of the air and dust precipitation (Städt. Gesundheitsdirektion [Municipal Public Health Administration] 1971). In 1972, this was expanded by the Geographic Institute into a climatological / atmospheric-hygiene measurement network (Enclosure 2) with the following goals:

-- first, processing of climatic / atmospheric-hygiene information as the basis for planning considerations. Although the main emphasis in the work is on the characterization of terrain and urban-climatology processes and functions (insolation, ventilation, thermals, precipitation, etc.), it is still necessary to include the interrelation of the atmospheric-hygiene hazard on the ground (air pollution, traffic emissions, location problems, etc.).

-- secondly, the development of methods which would allow such complex problems to be handled within given time limits in the future. One project is aimed at evaluation methods, another at measurement methods. In evaluation methodology, we are always presented with the question of the extent to which a long-term series of data from a station can be correlated with a short-term series of measurements from a large number of stations; in other words, the problem of timewise significance. To this is added the question of the extent to which one station or measurement network is representative of a given region and the validity with which ideas worked out in the form of a model can be transferred from one area to another; in other words, the problem of regional significance.

In measurement methodology, a trend is apparent in our conurbation areas toward setting up fully automatic measurement and monitoring systems with EDP. If we succeed in determining the most representative station locations through a comprehensive climatological / atmospheric-hygiene study, we would be able to have the entire "air space" of our environment under our supervision with just a few automatic stations. With a view toward such developments, we put the first such system into operation at the end of 1972, with a central unit in the Geographic Institute and an outside station at Eiger Plaza (system by Ott, Kempten). It should thus be possible to establish the processes and interactions between the urban climates, air pollution and planning measures through the application of arbitrarily selectable measurement intervals and rapid evaluation.

In conclusion, however, we would like to refer in summary form to a problem which extends far beyond our work and includes the questions posed at the beginning. With our terrestrial and aerial measurement program, it would indeed be possible to quantify all climatic / atmospheric-hygiene parameters of our nearby environment. But we cannot determine the subjective perceptions of the individual (quality of life) with such data alone. We would therefore have to know the effects of the environment upon man, in order to plan the future effects of man on the environment. But these problems will demand new collaboration among /74
the widest variety of disciplines, authorities and jurisdictions. Couldn't the Bern conurbation become a model case of this?

Summary

Problem

How have the extensive structural changes in our conurbation areas (58% of the population in 9% of the area) affected natural conditions, and how should natural environmental conditions be taken into consideration in future planning processes? We have concentrated on the subordinate area of climatic / atmospheric-hygiene problems and processes in the Bern area. At the present point in our work, we must limit ourselves to a few selected problems and preliminary results.

2. Insolation Time, Cloudiness and Fog in the SW [sic] Bern Area (Enclosure 1)

4

Insolation, the most important element in terms of bioclimate and urban planning, was covered over a test area of 49 km^2. The annual values for effective possible insolation time are shown on a map (Enclosure 1). A digital code provides local data on the effects of masking of the horizon on the seasonal and daily numbers of hours of insolation. The extent to which the sun is hidden by clouds and fog can be estimated with the aid of an isopleth mode of representation. Since fog is subject to variations in frequency and type of occurrence which are significant over even small areas and is of great importance to man, its distribution has been shown on a special map.

3. Wind Conditions in the Bern Area

Not only a knowledge of the prevailing winds but also frequency and velocity at different times of day are important for evaluating atmospheric-hygiene conditions. Hourly wind data from the Bern climatological station exhibit a typical daily pattern for the entire year. While the inflow of air takes place primarily from the Aare Valley at night, W and WE winds prevail during the day, the openings into the metropolitan area provided by topography (Wangen Valley, Wohlen Lake graben and Zollikofen corridor) functioning as the principal ventilation channels here. The importance of relief for ventilation and thus for questions of location (emission and immission) is demonstrated particularly with comparative measurements between Bantiger and Bolligen.

4. Temperature Series Over Many Years and Regional Temperature Differentiation

Long-term annual means, monthly means, mean minima and maxima and absolute minima and maxima are shown for Bern (MZA station).

These data are hardly significant for thermal differentiation in a conurbation, however. The month of November is used as an example to show the problems which can occur in vertical terms (inversion: Bantiger and Aare River stations) and in horizontal terms (thermal island: Zollikofen and Bern MZA stations). The city's thermal island is characterized with a temperature difference of about 2°, but it should be studied even more exactly with special consideration given to weather conditions and various climatic and atmospheric-hygiene elements.

5. Snow Coverage Conditions

Snow coverage in the Swiss midland does not have a reliable long-term mean and fluctuates between 10 and 86 snow days (average of 47), as is shown in the example of the Bern MZA station for the /75 period of 1920 to 1970. A blanket of snow can be expected with more than 50% probability for only 20 days per winter. The range between 800 and 1000 m above sealevel probably represents the transition zone from the primarily weather-dependent snow coverage of the lower midland to a permanent blanket of snow guaranteed on the long-term average in higher locations.

6. Earth Observation from Space

Climate studies will also be possible within a regional framework in the future, in part with the aid of data from satellite sensors, as is shown in the example of pictures from the ERTS-1 earth research satellite. Snow lines, cloudiness and upper limits on fog masses can be determined with a precision of ±50 or 100 m, and hazes and their extent can be determined over large areas in the proper spectral region.

7. Climatological / Atmospheric-Hygiene Measurement Network (Enclosure 2)

Although principal emphasis in this work has been placed on terrain and urban-climatology problems, it is still necessary to consider the interrelationship with the atmospheric-hygiene problem on the ground. Particular attention should be devoted to methodological problems, particularly that of timewise significance (correlation of long-term series with short-term measurement programs) and regional significance (transfer of data or models to other areas). Fully automated stations and EDP (arbitrary measurement intervals, rapid evaluation) should permit urban climate and air pollution to be monitorable in the future and predictable to a certain degree. They must be taken into consideration in our planning activities.

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